Growth curves of crossbred cows sired by Hereford, Angus, Belgian Blue, Brahman, Boran, and Tuli bulls, and the fraction of mature body weight and height at puberty[1,2]

H. C. Freetly,[3] L. A. Kuehn, and L. V. Cundiff

USDA, ARS, US Meat Animal Research Center, Clay Center, NE 68933

ABSTRACT: The objective of this study was to evaluate the growth curves of females to determine if mature size and relative rates of maturation among breeds differed. Body weight and hip height data were fitted to the nonlinear function BW = f(age) = A − Be$^{k \times age}$, where A is an estimate of mature BW and k determines the rate that BW or height moves from B to A. Cows represented progeny from 28 Hereford, 38 Angus, 25 Belgian Blue, 34 Brahman, 8 Boran, and 9 Tuli sires. Bulls from these breeds were mated by AI to Angus, Hereford, and MARC III composite (1/4 Angus, 1/4 Hereford, 1/4 Red Poll, and 1/4 Pinzgauer) cows to produce calves in 1992, 1993, and 1994. These matings resulted in 516 mature cows whose growth curves were subsequently evaluated. Hereford-sired cows tended to have heavier mature BW, as estimated by parameter A, than Angus- ($P = 0.09$) and Brahman-sired cows ($P = 0.06$), and were heavier than the other breeds ($P < 0.001$). Angus-sired cows were heavier than Boran- ($P < 0.001$) and Tuli-sired cows ($P < 0.001$), and tended to be heavier than Belgian Blue-sired cows ($P = 0.097$). Angus-sired cows did not differ from Brahman-sired cows ($P = 0.94$). Brahman-sired cows had a heavier mature BW than Boran- ($P < 0.001$), Tuli- ($P < 0.001$), and Belgian Blue-sired cows ($P < 0.04$). Angus-sired cows matured faster (k) than cows sired by Hereford ($P = 0.03$), Brahman ($P < 0.001$), Boran ($P = 0.03$), and Tuli ($P < 0.001$) sires, but did not differ from Belgian Blue-sired ($P = 0.13$) cows. Brahman-sired cows took longer to mature than Boran- ($P = 0.03$) or Belgian Blue-sired cows ($P = 0.003$). Belgian Blue-sired cows were faster maturing than Tuli-sired cows ($P = 0.02$). Brahman-sired cows had reached a greater proportion of their mature BW at puberty than had Hereford- ($P < 0.001$), Tuli- ($P = 0.003$), and Belgian Blue-sired cows ($P = 0.001$). Boran-sired cows tended to have reached a greater proportion of their mature BW at puberty than had Angus-sired cows ($P = 0.09$), and had reached a greater proportion of their mature BW at puberty than had Hereford- ($P < 0.001$), Tuli- ($P < 0.001$), and Belgian Blue-sired cows ($P < 0.001$). Within species of cattle, the relative range in proportion of mature BW at puberty (*Bos taurus* 0.56 through 0.58, and *Bos indicus* 0.60) was highly conserved, suggesting that proportion of mature BW is a more robust predictor of age at puberty across breeds than is absolute weight or age.

Key words: beef cow, growth, maturity, puberty

J. Anim. Sci. 2011. 89:2373–2379
doi:10.2527/jas.2011-3847

INTRODUCTION

A considerable amount of the cow-calf beef production in the United States occurs in subtropical and arid regions. Breeds of cattle that are heat tolerant have an advantage in these environments. The Brahman breed and composite breeds developed from the Brahman breed have been major contributors to the germplasm used in cow-calf herds in areas that benefit from heat-tolerant cattle. Three heat-tolerant breeds (Brahman, Boran, and Tuli) were evaluated (USMARC GPE Cycle V) along with Hereford, Angus, and Belgian Blue breeds to determine the merit of non-Brahman heat-tolerant breeds. Like the Brahman, the Boran is a *Bos indicus*. The Tuli is a Sanga (*Bos taurus*) type. The Belgian Blue has been selected for muscling, which has resulted in an increase frequency of a gene that results in double muscling (*GDF8*). Growth traits and young-cow traits have been reported for these cattle (Freetly

[1]Mention of a trade name, proprietary product, or specific equipment does not constitute a guarantee or warranty by the USDA and does not imply approval to the exclusion of other products that may be suitable.

[2]USDA is an equal opportunity provider and employer.

[3]Corresponding author: Harvey.Freetly@ars.usda.gov

Received January 5, 2011.
Accepted March 16, 2011.

and Cundiff, 1997, 1998). Previous research has demonstrated that heifers need to reach a minimum BW and age before they will express puberty, and that age and BW differ with breed (Laster et al., 1976, 1979; Ferrell, 1982; Freetly and Cundiff, 1997). Futhermore, it has been shown that *B. indicus* cattle need to reach a greater proportion of their mature size before becoming pubertal (Gregory et al., 1979; Jenkins et al., 1991). The objective of this study was to evaluate the growth curves of females to determine if mature size and relative rates of maturation differed among breeds.

MATERIALS AND METHODS

The experiment was conducted to conform with the Guide for the Care and Use of Agricultural Animals in Agricultural Research and Teaching (FASS, 1999) and was approved by the US Meat Animal Research Center Animal Care and Use Committee.

Populations and management of females during early development have been described (Freetly and Cundiff, 1997, 1998). Heifers that were feed restricted were excluded from this evaluation, and only cows above at least 5 yr of age were included in this evaluation. Age at puberty did not differ ($P = 0.37$) between cows that successfully reached 5 yr of age and those that did not. Cows represented progeny from 28 Hereford, 38 Angus, 25 Belgian Blue, 34 Brahman, 8 Boran, and 9 Tuli sires. Bulls from these breeds were mated by AI to Angus, Hereford, and MARC III composite (1/4 Angus, 1/4 Hereford, 1/4 Red Poll, and 1/4 Pinzgauer) cows to produce calves in 1992, 1993, and 1994. These matings resulted in 516 mature cows, whose growth curves were subsequently evaluated (Table 1).

Calves were weighed at birth and at 9 additional times from weaning until breeding as heifers, and then twice a year as cows through 5 yr of age. Cow BW were taken at the beginning of breeding (May) and then again 4 mo later. Hip heights were taken at weaning (27 wk), at 1 yr of age, and at each subsequent BW measurement. When cows were weighed, BCS were taken using a 9-point scale (1 = thin; 9 = obese). Average mature BCS was calculated as an individual average BCS from 3 through 5 yr of age. Age at puberty was determined as the age that heifers first expressed behavioral estrus. Heifers were checked in the morning and afternoon for detection of estrus (Freetly and Cundiff, 1997). Puberty was detected in 488 of the 516 cows.

Individual growth curves for BW and hip height on age (wk) were fitted with a nonlinear function that Brody (1964) has described previously (Eq. [1]):

$$f(\text{age}) = \text{A} - \text{B}e^{\text{k}\times\text{age}}. \quad [1]$$

Individual animal parameter estimates for A, B, and k were determined using the NLIN function (SAS Inst. Inc., Cary, NC). Parameter A represents the asymptote of the equation, parameter B represents the units between the value at 0 d of age and parameter A, and parameter k determines the rate that the response variable moves from B to A. Gauss-Newton iterations were used to minimize the error sums of squares. Body weight and hip height at puberty were calculated within individual cows by solving Eq. [1] at the age at puberty. Proportion of mature BW and proportion of mature hip height at puberty were calculated within individual cows by dividing Eq. [1] by the parameter estimate for A (Eq. [2]) solving for the age at puberty:

$$f(\text{age}) = 1 - (\text{B}/\text{A})e^{\text{k}\times\text{age}}. \quad [2]$$

Breed differences for the estimated values of the parameters were analyzed with a mixed model in which sire breed, dam breed, birth year, sire breed × birth year, and dam breed × birth year were fixed effects, and sire nested within sire breed was a random effect.

RESULTS AND DISCUSSION

Richards (1959) reported several functions that could be used to describe growth in plants empirically. These growth functions in general describe the rate of growth decreasing logistically as an organism ages, and indicate that mature size approaches an asymptote. These functions describe growth as a sigmoid process and differ primarily in how the inflection point is described. Brody (1964) described the use of the simplest form of these equations (Eq. [1]) to describe growth in animals. Higher order functions that defined an inflection point were tested with this data set; however, absences of data between birth and the inflection point did not yield unique solutions for the parameter estimates, re-

Table 1. Breed composition of cows

	Dam breed			
Sire breed	Hereford	Angus	MARC III	Total
Hereford	—	25	49	74
Angus	12	—	65	77
Belgian Blue	11	33	66	110
Brahman	12	21	47	80
Boran	11	31	39	81
Tuli	11	26	57	94
Total	57	136	323	516

sulting in the selection of the simplest form that did not include an inflection point. Parameter A describes the asymptote and is considered to be mature size. Parameter estimate k describes the rate that growth occurs over the span of change in size (parameter B). Both skeletal size and BW as a function of time can be described by Eq. [1]. An inherit assumption in using this family of curves is that substrate for growth (feed) is not limiting. Because the heifers reared on restricted intakes (Freetly and Cundiff, 1997) violate this assumption, they were excluded from the data set. There was an interaction between birth year and sire breed for mature BCS ($P = 0.03$). Mature BCS for Hereford-, Angus-, Belgian Blue-, Brahman-, Boran-, and Tuli-sired cows were 6.5 ± 0.2, 6.1 ± 0.2, 5.3 ± 0.1, 6.5 ± 0.1, 6.8 ± 0.1, and 6.5 ± 0.1 for cows born in 1992; 5.9, 6.1, 4.7, 6.6, 6.6, 6.4 ± 0.1 for cows born in 1993; and 6.5, 6.3, 5.0, 6.9, 6.7, 6.4 ± 0.1 for cows born in 1994. Cows that had Hereford dams (6.5 ± 0.08) had greater mature BCS than cows with Angus (6.2 ± 0.05; $P = 0.003$) or MARC III dams (6.1 ± 0.04; $P < 0.001$).

BW

Analyses of residuals indicated a bias in the residuals for birth weight, suggesting that the equation does not adequately predict birth weight; however, with birth weights excluded from the data, analyses of the residuals indicated that the Brody function fit the BW data. The slope of observed BW on predicted BW, excluding birth weight, was 0.99 ± 0.002. The mean residual estimate was positive (0.6 ± 0.2 kg; $P = 0.004$), and there was a slight trend for the model to overpredict BW as predicted BW increased (Figure 1). Hereford-sired cows tended to have heavier mature BW as estimated by parameter A than did Angus- ($P = 0.09$) and Brahman-sired cows ($P = 0.06$), and were heavier than the other breeds ($P < 0.001$; Figure 2A). Angus-sired cows were heavier than Boran- ($P < 0.001$) and Tuli-sired cows ($P < 0.001$), and tended to be heavier than Belgian Blue-sired cows ($P = 0.097$; Figure 2A). Angus-sired cows did not differ from Brahman-sired cows ($P = 0.94$; Figure 2A). Brahman-sired cows had a heavier mature BW than Boran- ($P < 0.001$), Tuli- ($P < 0.001$), and Belgian Blue-sired cows ($P < 0.04$; Figure 2A). The mature BW of Belgian Blue-sired cows were heavier than those of Boran- ($P < 0.001$) and Tuli-sired cows ($P < 0.001$; Figure 2A).

Jenkins et al. (1991) used the same function for growth to evaluate growth curves of crossbred cows that were born from 1970 through 1976. The study by Jenkins et al. (1991) evaluated cows sired by 16 different sire breeds and reported parameter A mean ± SD estimates for Angus (512 ± 40 kg), Hereford (500 ± 37 kg), and Brahman (550 ± 42 kg). The results from Jenkins et al. (1991) and our study show that mature cow BW of all 3 breeds increased (26 to 98 kg; Figure 2A) between the evaluation conducted in the 1970s and that conducted in the 1990s. The evaluations of both Jenkins et al. (1991) and Arango et al. (2002), who used the same population of cattle to estimate age effects on BW, demonstrated that Brahman-cross cows sampled in the 1970s weighed more than Hereford- and Angus-cross cows. Our study, based on sampling these same breeds in the 1990s, suggests that with the increase in mature BW between the 2 studies, the differences between the 3 breeds no longer exist or are reranked. These estimates reflect one-half of the genetic trends that would be expected among purebred cattle. There was no dam breed effect on mature BW ($P < 0.45$).

The parameter k determines the rate that growth occurs over the parameter estimate B, and can be interpreted as a measure of the rate of maturation. Angus-sired cows matured faster than cows sired by Hereford ($P = 0.03$), Brahman ($P < 0.001$), Boran ($P = 0.03$), and Tuli ($P < 0.001$) sires, but did not differ from Belgian Blue-sired cows ($P = 0.13$; Figure 2B). Brahman-sired cows took longer to mature than Boran- ($P = 0.03$) or Belgian Blue-sired cows ($P = 0.003$; Figure 2B). Belgian Blue-sired cows were faster maturing than Tuli-sired cows ($P = 0.02$). Cows with Hereford dams (k = −0.01390 ± 0.00041) were slower to mature than cows with Angus (k = −0.01579 ± 0.00026; $P < 0.001$) or MARC III (k = −0.01559 ± 0.00020, $P < 0.001$) dams.

Hip Height

Another measure of maturity is skeletal size. The overall function described in Eq. [1] fit the hip height data. The slope of observed hip height on predicted hip height was 1.00 ± 0.003. The mean residual did not

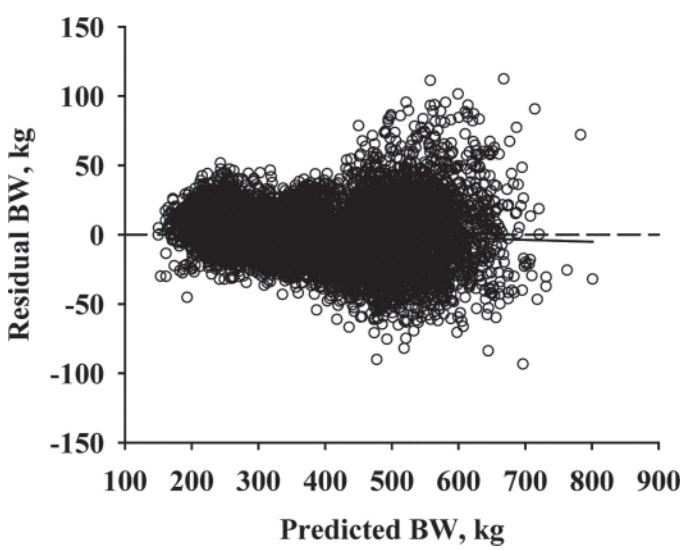

Figure 1. Residuals for BW (excluding birth weight) using the following equation fit to individual animals: $f(\text{age}) = A - Be^{k \times \text{age}}$, where parameter A represents the asymptote of the equation, parameter B represents the units between the value at 0 d of age and parameter A, and parameter k determines the rate that the response variable moves from B to A. Mean residual was 0.58 ± 0.21 ($P_{H \neq 0} = 0.004$). Regression of residuals on predicted BW: slope = −0.014 ± 0.002, intercept 5.92 ± 0.71.

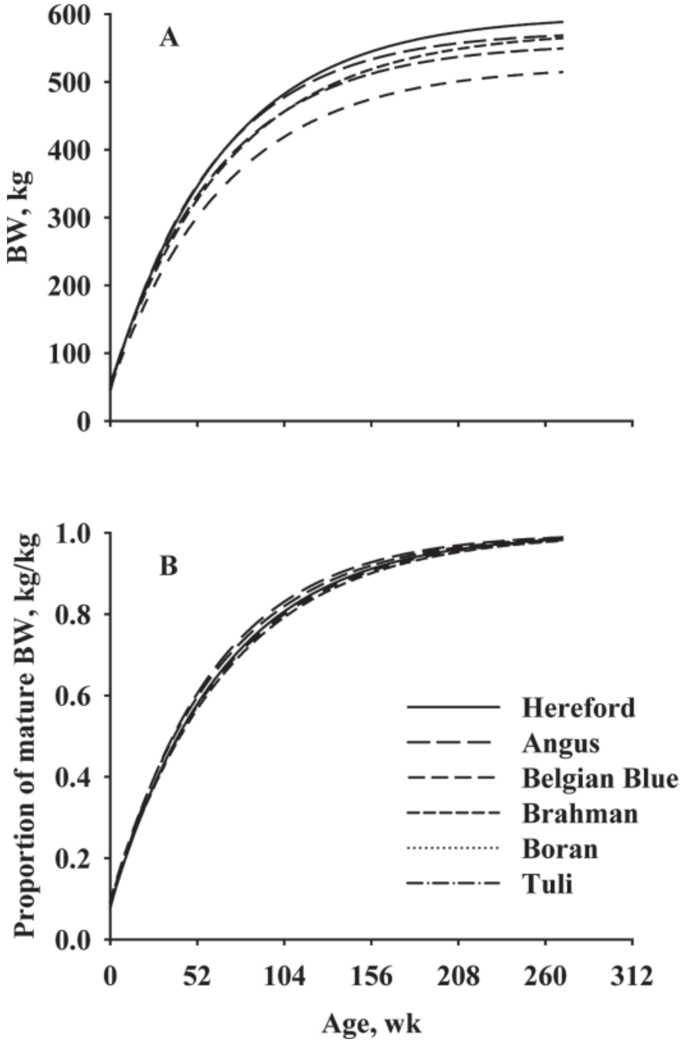

Figure 2. Sire breed effects on BW growth curves of crossbred cows. A) Relationship between BW (kg) and age (wk) of Hereford $[(598 \pm 9) - (549 \pm 9)e^{(-0.0150 \pm 0.0004)\text{age}}]$, Angus $[(575 \pm 10 - 531 \pm 9) e^{(-0.0163 \pm 0.0005)\text{age}}]$, Belgian Blue $[(557 \pm 6) - (504 \pm 6)e^{(-0.01549 \pm 0.0003)\text{age}}]$, Brahman $[(576 \pm 8) - (522 \pm 7)e^{(-0.0142 \pm 0.0004)\text{age}}]$, Boran $[(515 \pm 7) - (463 \pm 6)e^{(-0.0151 \pm 0.0003)\text{age}}]$, and Tuli $[(524 \pm 6) - (476 \pm 10) e^{(-0.0145 \pm 0.0003)\text{age}}]$ cross cows. B) Relationship between proportion of mature BW (kg/kg) and age (wk) of Hereford $[1 - (0.919 \pm 0.003) e^{(-0.0150 \pm 0.0004)\text{age}}]$, Angus $[1 - (0.922 \pm 0.003)e^{(-0.0163 \pm 0.0005)\text{age}}]$, Belgian Blue $[1 - (0.905 \pm 0.002)e^{(-0.01549 \pm 0.0003)\text{age}}]$, Brahman $[1 - (0.905 \pm 0.003)e^{(-0.0142 \pm 0.0004)\text{age}}]$, Boran $[1 - (0.898 \pm 0.002)e^{(-0.0151 \pm 0.0003)\text{age}}]$, and Tuli $[1 - (0.908 \pm 0.002)e^{(-0.0145 \pm 0.0003)\text{age}}]$ cross cows.

differ from 0 (0.00 ± 0.02; $P = 1.00$), and the slope of residuals on predicted heights did not differ from 0 ($P = 1.00$; Figure 3). Because the first hip height measurements were taken at 6 mo of age, extrapolations of the function to predict height in calves younger than 6 mo of age is not appropriate. The mature height of Brahman-sired cows was greater than that of cows sired by other breeds ($P < 0.001$; Figure 4A). With the exception of Brahman-sired cows, Hereford-sired cows were taller than cows sired by other breeds ($P < 0.001$ to 0.03). Angus-sired cows were taller than Boran- ($P = 0.03$) and Tuli-sired cows ($P = 0.03$; Figure 4A). Belgian Blue-sired cows were taller than Boran- ($P = 0.05$) and Tuli-sired cows ($P = 0.02$; Figure 4A). Consistent with the increase in BW, hip heights increased in cows sired by bulls sampled in the 1990s compared with bulls sampled in the 1970s (Jenkins et al., 1991; Arango et al., 2002). Jenkins et al. (1991) reported mature hip heights (mean ± SD) of Angus- (124 ± 3 cm), Hereford- (123 ± 3 cm), and Brahman-sired cows (132 ± 4 cm). The Brahman-sired cows ranked taller both for cows sampled in the 1970s and for cows sampled in the 1990s. Since the study by Jenkins et al. (1991), the relative increase in hip height has become greater for Hereford-sired cows. Cows with MARC III dams (133.9 ± 0.3 cm) were taller than cows with Angus dams (132.4 ± 0.3 cm; $P < 0.001$). Neither sire breeds ($P = 0.25$; Figure 4B) nor dam breeds ($P = 0.90$) differed in the rate of maturation. Cows born in 1992 were slower to mature than were cows born in 1994 ($P = 0.002$).

Puberty

The puberty data in the current study (Table 2) are for cows that successfully reached 5 yr of age, and, as such, they are a consistent subset of the total puberty data collected in the breed evaluation (Freetly and Cundiff, 1997). Age at puberty for the subset data are reported in Table 2.

Body weight at puberty was calculated using Eq. [1] as a function of age at puberty. The ability of the model to fit the data was tested, evaluating residuals from BW taken between 4 wk before and 4 wk after a heifer expressed puberty. The slope of observed BW on predicted BW was 1.03 ± 0.01. Mean residual differed from 0 (−1.11 ± 0.37 kg; $P = 0.002$), and the slope of

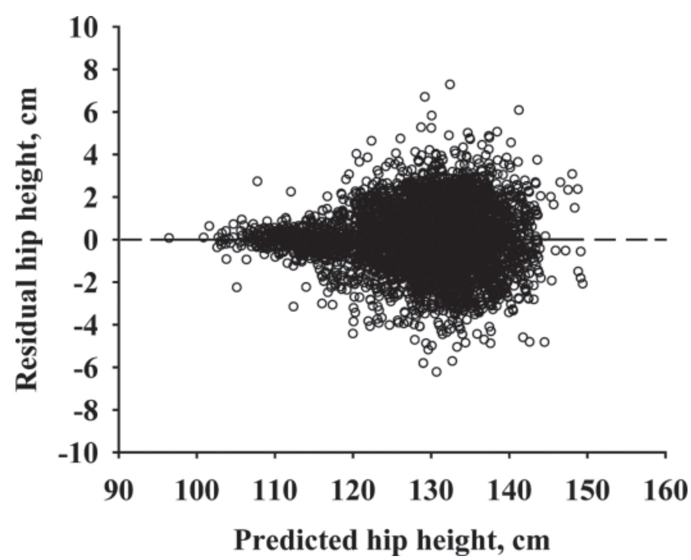

Figure 3. Residuals for hip height using the following equation fit to individual animals: $f(\text{age}) = A - Be^{k \times \text{age}}$, where parameter A represents the asymptote of the equation, parameter B represents the units between the value at 0 d of age and parameter A, and parameter k determines the rate that the response variable moves from B to A. Means residual was 0.00 ± 0.02 ($P_{H \neq 0} = 1.00$). Regression of residuals on predicted hip height: slope = 0.00 ± 0.003, intercept 0.00 ± 0.35.

Table 2. Characteristics at puberty

Item	Age, wk	BW, kg	Hip height, cm	Proportion of mature BW	Proportion of mature height
Sire breed					
Hereford	49.8 ± 0.7	333 ± 5	121.1 ± 0.5	0.557 ± 0.010	0.902 ± 0.003
Angus	49.6 ± 0.7	333 ± 5	119.8 ± 0.5	0.582 ± 0.010	0.903 ± 0.003
Belgian Blue	48.5 ± 0.5	312 ± 3	119.0 ± 0.4	0.566 ± 0.007	0.901 ± 0.002
Brahman	58.2 ± 0.6	343 ± 4	126.5 ± 0.4	0.600 ± 0.008	0.922 ± 0.003
Boran	54.8 ± 0.5	307 ± 4	120.5 ± 0.4	0.603 ± 0.007	0.919 ± 0.002
Tuli	52.1 ± 0.5	295 ± 3	119.1 ± 0.4	0.569 ± 0.007	0.910 ± 0.002
P-value for sire breed[1]	<0.001	<0.001	<0.001	<0.001	<0.001

[1]Probability that the sire breeds differ.

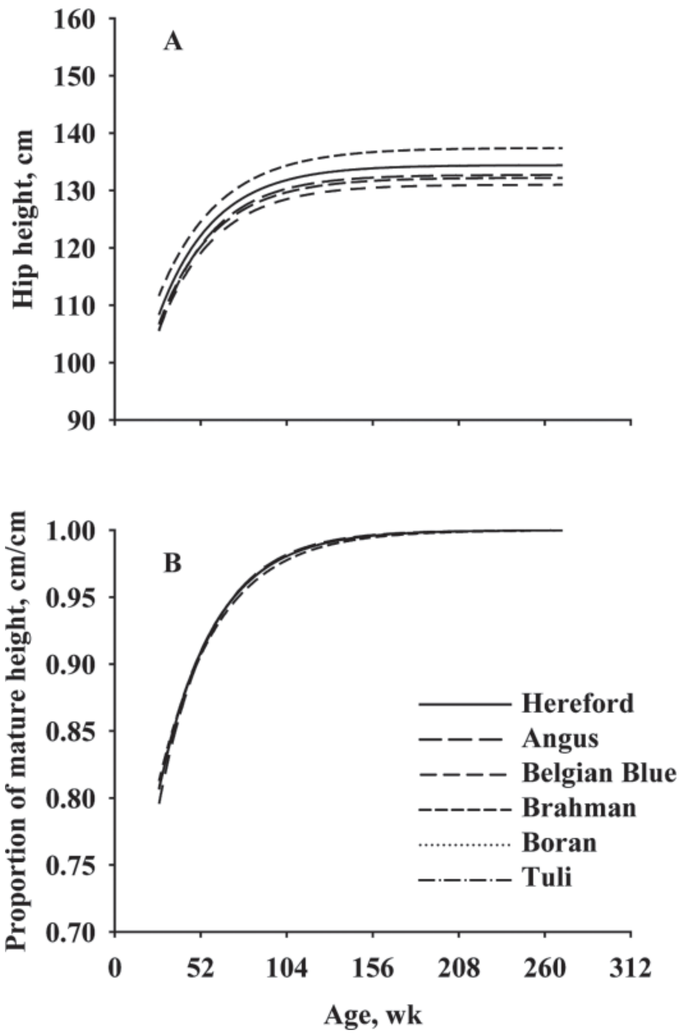

Figure 4. Sire breed effects on hip height growth curves of crossbred cows from 27 wk to 5 yr of age. A) Relationship between hip height (cm) and age (wk) of Hereford $[(134.4 \pm 0.5) - (58.0 \pm 4.2)e^{(-0.0298 \pm 0.0012)\text{age}}]$, Angus $[(132.7 \pm 0.7 - 62.9 \pm 4.4)e^{(-0.0313 \pm 0.0013)\text{age}}]$, Belgian Blue $[(132.2 \pm 0.4) - (56.8 \pm 3.0)e^{(-0.0299 \pm 0.0009)\text{age}}]$, Brahman $[(137.4 \pm 0.4) - (53.9 \pm 3.5)e^{(-0.0276 \pm 0.0010)\text{age}}]$, Boran $[(131.1 \pm 0.4) - (56.8 \pm 3.0)e^{(-0.0298 \pm 0.0009)\text{age}}]$, and Tuli $[(131.0 \pm 4) - (56.3 \pm 2.9)e^{(-0.0298 \pm 0.0008)\text{age}}]$ cross cows. B) Relationship between proportion of mature hip height (cm/cm) and age (wk) of Hereford $[1 - (0.43 \pm 0.03)e^{(-0.0298 \pm 0.0012)\text{age}}]$, Angus $[1 - 0.47 \pm 0.03)e^{(-0.0313 \pm 0.0013)\text{age}}]$, Belgian Blue $[1 - (0.43 \pm 0.02)e^{(-0.0299 \pm 0.0009)\text{age}}]$, Brahman $[1 - (0.39 \pm 0.03)e^{(-0.0276 \pm 0.0010)\text{age}}]$, Boran $[1 - (0.43 \pm 0.02)e^{(-0.0298 \pm 0.0009)\text{age}}]$, and Tuli $[1 - (0.43 \pm 0.02)e^{(-0.0298 \pm 0.0008)\text{age}}]$ cross cows.

residuals on predicted BW differed from 0 ($P = 0.002$; Figure 5A). Although both the mean and the regression analysis suggested a bias in the residuals, the magnitude of the bias was relatively small. Brahman-sired cows tended to be heavier at puberty than Angus-sired cows ($P = 0.08$), and were heavier than Boran-, Tuli-, and Belgian Blue-sired cows ($P < 0.001$; Table 2). Both Hereford- and Angus-sired cows were heavier at puberty than Boran-, Tuli-, and Belgian Blue-sired cows ($P < 0.001$; Table 2). Tuli-sired cows were lighter in BW at puberty than Boran- ($P < 0.01$) and Belgian Blue-sired cows ($P < 0.001$; Table 2). Cows with Hereford dams (308 ± 5 kg) had lighter BW at puberty than cows with Angus (329 ± 3 kg; $P < 0.001$) and MARC III dams (325 ± 2 kg; $P = 0.001$). Gregory et al. (1979) reported that Brahman-sired heifers were heavier at puberty than Hereford- and Angus-sired heifers.

Brahman-sired cows had reached a greater proportion of their mature BW at puberty than had Hereford- ($P < 0.001$), Tuli- ($P = 0.003$), and Belgian Blue-sired cows ($P = 0.001$; Table 2). Boran-sired cows tended to have reached a greater proportion of their mature BW at puberty compared with Angus-sired cows ($P = 0.09$), and had reached a greater proportion of their mature BW at puberty than had Hereford- ($P < 0.001$), Tuli- ($P < 0.001$), and Belgian Blue-sired cows ($P < 0.001$, Table 2). Cows with Hereford dams (0.549 ± 0.010 kg) had reached a smaller proportion of their mature BW at puberty than had cows with Angus (0.600 ± 0.006 kg; $P < 0.001$) and MARC III dams (0.589 ± 0.004 kg; $P < 0.001$). Using the BW at puberty reported by Gregory et al. (1979) and the estimated mature BW reported for the same cattle by Jenkins et al. (1991), we can estimate that Brahman-sired cows reached puberty at 61% of their mature BW, which is an estimate similar to that reported in this study (60%). Borans, the other *B. indicus* breed evaluated in this study, had reached 60% of their mature BW at puberty, suggesting that *B. indicus* cattle reach puberty at a greater percentage of their mature BW compared with *B. taurus* cattle. The proportion of mature BW is a measure of the physiological age of the animal. These studies suggest that *B. indicus* cattle are older chronologically and physiologically than *B. taurus* cattle when they reach puberty. Hereford- and Angus-sired cattle reached pu-

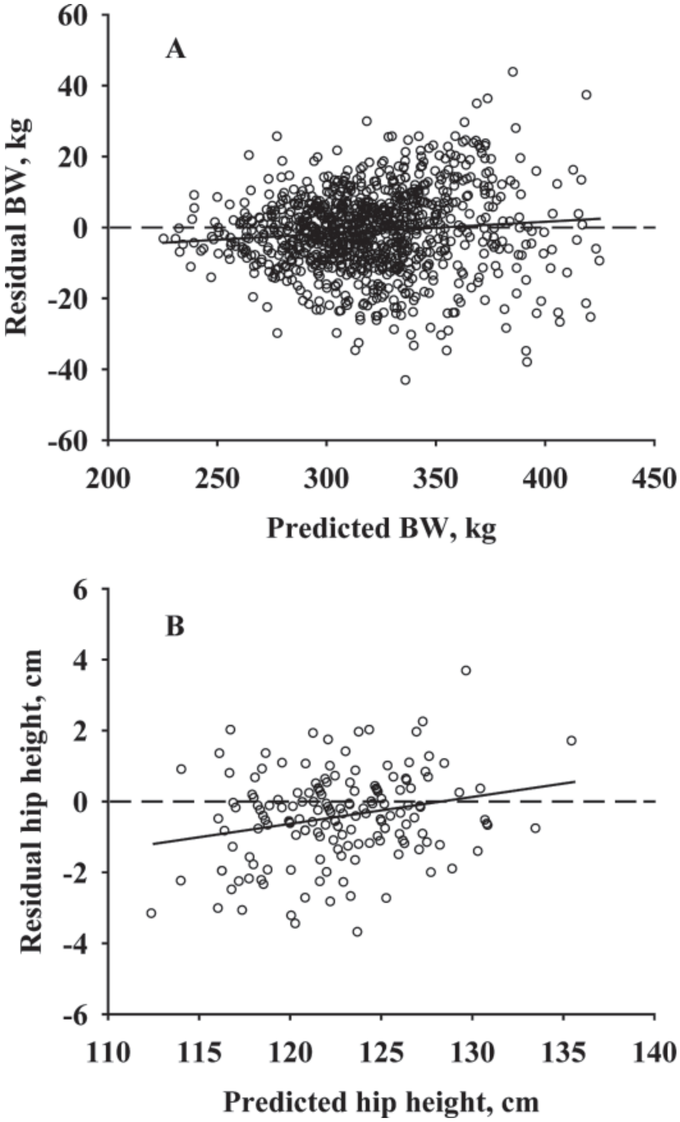

Figure 5. Residuals for 4 wk before and after a heifer reaches puberty using the following equation fit to individual animals: $f(\text{age}) = \text{A} - \text{B}e^{\text{k}\times\text{age}}$, where parameter A represents the asymptote of the equation, parameter B represents the units between the value at 0 d of age and parameter A, and parameter k determines the rate that the response variable moves from B to A. A) Residuals for BW (kg). Means residual was -0.43 ± 0.10 ($P_{\text{H}\neq 0} < 0.001$). Regression of residuals on predicted BW: slope = -0.08 ± 0.02, intercept -9.70 ± 2.96. B) Residuals for hip height (cm). Means residual was -0.45 ± 0.10 ($P_{\text{H}\neq 0} < 0.001$). Regression of residuals on predicted hip height: slope = -0.07 ± 0.02, intercept -9.60 ± 2.96.

berty at a similar proportion of their mature BW between this study and earlier evaluations (Gregory et al., 1979; Jenkins et al., 1991) in spite of the fact that mature BW increased for Hereford- and Angus-sired cows between the 2 studies. These findings suggest that the desired minimum target BW established for heifers at puberty can become erroneous as selection pressure for mature size changes, and that the minimum target BW at puberty should be determined as a function of mature BW.

Hip height at puberty was calculated using Eq. [1] as a function of age at puberty. The ability of the model to fit the data was tested by evaluating residuals from hip heights taken between 4 wk before and 4 wk after a heifer expressed puberty. The slope of observed hip heights on predicted heights was 1.07 ± 0.02. Mean residual differed from 0 (-0.43 ± 0.10 cm; $P < 0.001$). The slope of residuals on predicted hip height differed from 0 ($P = 0.002$; Figure 5B). Brahman-sired cows were taller at puberty than cows sired by other breeds ($P < 0.001$; Table 2). Sacco et al. (1987) reported the same finding when comparing Brahman heifers with Hereford, Angus, Holstein, and Jersey heifers. There was a tendency for Hereford-sired cows to be taller at puberty than Angus-sired cows ($P = 0.07$), and they were taller than Tuli- ($P < 0.001$) and Belgian Blue-sired cows ($P < 0.001$; Table 2). Boran-sired cows were taller at puberty than Tuli- ($P = 0.004$) and Belgian Blue-sired cows ($P < 0.003$; Table 2). Cows with MARC III dams (121.9 ± 0.2 cm) were taller at puberty than cows with Hereford dams (120.2 ± 0.5 cm; $P = 0.002$) and Angus dams (120.9 ± 0.3 cm; $P = 0.01$).

With the exception of Boran-sired cows ($P = 0.45$), Brahman-sired cows had reached a greater proportion of their mature hip height at puberty than had the other breeds ($P < 0.001$; Table 2). Boran-sired cows had reached a greater proportion of their mature height at puberty than had Hereford- ($P < 0.001$), Angus- ($P < 0.001$), Tuli- ($P = 0.004$), and Belgian Blue-sired cows ($P < 0.001$; Table 2). Tuli-sired cows had reached a greater proportion of their mature height than had Hereford- ($P = 0.02$), and Belgian Blue-sired cows ($P = 0.001$), and tended to be greater than Angus-sired cows ($P = 0.056$; Table 2) at puberty. Cows born in 1992 (0.919 ± 0.003) reached a greater proportion of mature height than cows born in 1993 (0.907 ± 0.002; $P = 0.001$) and 1994 (0.902 ± 0.003; $P < 0.001$).

Both skeletal size and BW can be used to estimate the relative maturity of animals. Tissues differ in the relative rates at which they reach their mature size (Brody, 1964). Cattle reach their mature skeletal size before they reach their mature BW. Like BW, the proportion of mature height obtained at puberty was greater for both the Brahman- and Boran-sired cows. These findings suggest that the earlier reports that Brahman cattle have reached a greater proportion of maturity at puberty (Gregory et al., 1979; Jenkins et al., 1991) may not be confined to Brahman cattle and may be characteristic of the broader class of *B. indicus* breeds. Within species of cattle, the relative range in proportion of mature BW at puberty (*B. taurus* 0.56 through 0.58, and *B. indicus* 0.60) was highly conserved, suggesting that proportion of mature BW is a more robust predictor of age at puberty across breeds than is absolute BW or age.

LITERATURE CITED

Arango, J. A., L. V. Cundiff, and L. D. Van Vleck. 2002. Breed comparisons of Angus, Brahman, Hereford, Pinzgauer, Sahiwal, and Tarentaise for weight, weight adjusted condition score, height, and body condition score. J. Anim. Sci. 80:3142–3149.

Brody, S. 1964. Bioenergetics and Growth. Hafner Publishing Company Inc., New York, NY.

FASS. 1999. Guide for the Care and Use of Agricultural Animals in Agricultural Research and Teaching. 1st rev. ed. Fed. Anim. Sci. Soc., Savoy, IL.

Ferrell, C. L. 1982. Effects of postweaning rate of gain on onset of puberty and productive performance of heifers of different breeds. J. Anim. Sci. 55:1272–1283.

Freetly, H. C., and L. V. Cundiff. 1997. Postweaning growth and reproduction characteristics of heifers sired by bulls of seven breeds and raised on different levels of nutrition. J. Anim. Sci. 75:2841–2851.

Freetly, H. C., and L. V. Cundiff. 1998. Reproductive performance, calf growth, and milk production of first-calf heifers sired by seven breeds and raised on different levels of nutrition. J. Anim. Sci. 76:1513–1522.

Gregory, K. E., D. B. Laster, L. V. Cundiff, G. M. Smith, and R. M. Koch. 1979. Characterization of biological types of cattle—Cycle III: II. Growth rate and puberty in females. J. Anim. Sci. 49:461–471.

Jenkins, T. G., M. Kaps, L. V. Cundiff, and C. L. Ferrell. 1991. Evaluation of between- and within-breed variation in measures of weight-age relationships. J. Anim. Sci. 69:3118–3128.

Laster, D. B., G. M. Smith, L. V. Cundiff, and K. E. Gregory. 1979. Characterization of biological types of cattle (Cycle II). II. Postweaning growth and puberty of heifers. J. Anim. Sci. 48:500–508.

Laster, D. B., G. M. Smith, and K. E. Gregory. 1976. Characterization of biological types of cattle IV. Postweaning growth and puberty of heifers. J. Anim. Sci. 43:63–70.

Richards, F. J. 1959. A flexible growth function for empirical use. J. Exp. Bot. 10:290–300.

Sacco, R. E., J. F. Baker, and T. C. Cartwright. 1987. Production characters of primiparous females of a five-breed diallel. J. Anim. Sci. 64:1612–1618.